

Basin-Scale Ocean Prediction System

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LONG-TERM GOALS

An eddy-resolving nowcast/forecast system for the global ocean with embedded basin-scale systems (1/16° Pacific north of 20°S and 1/32° Atlantic subtropical gyre, 9°-51°N, which includes the Intra-Americas Sea) and a global model with progressively increasing resolution, 1/4°, 1/8° and ultimately 1/32° resolution. These systems will include data assimilation of satellite altimetry, sea surface temperature and in-situ data.

OBJECTIVES

The development and validation of basin and global scale ocean prediction systems. This includes skillful nowcasts and forecasts of ocean thermal structure and currents. High horizontal resolution is required 1) to depict eddies and meandering inertial jets/oceanic fronts which can span large ocean basins, 2) to provide boundary conditions for coastal models with even higher resolution and 3) for upper ocean - topographic coupling via mesoscale flow instabilities. The latter is required for accurate positioning of current systems including the Gulf Stream and Kuroshio. The modeling effort focuses on the development and validation of the NRL Layered Ocean Model (NLOM) for the Global, subtropical Atlantic and North Pacific basins which supports planned 6.4 transitions.

Observations with unprecedented accuracy and resolution of the global ocean surface are now being made by satellite-borne altimeters and AVHRR sensors. Up to five existing and approved altimeter missions will be orbiting simultaneously for the next several years. The Naval Oceanographic Office's Altimetry Data Fusion Center (ADFC) is distributing processed data from these sensors to operational users in near real time. Previous studies and demonstrations by NRL have shown that accurate nowcasts of much of the ocean's density and currents is possible given only an accurate estimate of sea surface height and sea surface temperature. Using statistical and the global observations, ocean nowcasts of naval interest are possible without numerical models and were demonstrated in FY97, however using the numerical models to improve the accuracy of the sea surface height fields will greatly improve the skill of the nowcasts. Our objective is to develop and demonstrate the improved capabilities for ocean nowcast/forecast systems, focused on the Global and Pacific basin using NLOM. These capabilities will be transitioned to FNMOC for operational Navy use.

APPROACH

The modeling effort is aimed at eddy-resolving models for the Atlantic and Pacific Oceans and associated model development in collaboration with other projects. A wide variety of model/data comparisons are performed for evaluation of assimilative and nonassimilative model experiments.

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Hydrodynamic and thermodynamic versions of NLOM are used with grid resolutions of $1/2^\circ$ to $1/32^\circ$ for each variable and 5 to 6 Lagrangian layers in the vertical. The model has a free surface and allows diapycnal mixing, isopycnal outcropping and inflow/outflow through ports in the model boundaries. A version which includes a mixed layer and sea surface temperature is under development. The model runs efficiently and interchangeably on all DOD HPC platforms designed to handle applications this large, including massively parallel distributed memory computers and multi-processor shared memory computers. In general, NLOM is the most efficient ocean model in existence in terms of computer time per model year.

The altimeter heights will be assimilated using a combination of optimum interpolation, statistical inference, and nudging. However, the methods will depend upon the model chosen. Past experience with parameter optimization in a Gulf Stream regional system indicates that substantial improvements in performance can be obtained by empirically adjusting parameters used in the assimilation methods. More advanced methods of assimilation such as the adjoint and Kalman filtering techniques have not yet reached a state where they are practical alternatives. Presently, they show only small improvements over standard methods, but at very high cost.

WORK COMPLETED

During FY98, the project had 19 publications (submitted to in print, excluding abstracts).

1. Continued development and fine-tuning of the $1/16^\circ$ thermodynamic, finite depth Pacific model. Numerous developmental experiments performed. Also provided four simulations forced by interannually varying FNMOC winds for initial data assimilation testing. Transitioned the research version of NLOM to the DART team.
2. Spun-up to near real-time, and provided to FNMOC the wind-forced $1/4^\circ$ global, thermodynamic, finite depth model for insertion into the operational runstream. This was the first generation version of OCEANS 2.0 and it did not include assimilation of satellite altimeter data. Also provided three simulations forced by interannually varying winds for initial data assimilation testing. Transitioned the research version of NLOM to the DART team.
3. Recently began development of the $1/8^\circ$ global, thermodynamic, finite depth model. This is the target resolution for the global eddy-resolving nowcast/forecast system scheduled for delivery at the end of FY00.
4. NLOM development continued. NLOM's diffusion options have been greatly expanded to include spatially varying Laplacian eddy viscosity, a smaller eddy viscosity in the lowest layer, and biharmonic diffusion for density and layer thickness. The model's scalability using MPI has been improved, particularly on the IBM SP, by algorithmic modifications and by tuning MPI calls.
5. Numerous $1/2^\circ$ global simulations were performed to evaluate and refine mixed layer embedment. The mixed layer can now either be confined to layer one (as before) or extend across multiple layers. The heat flux formulation has been improved based on global statistics.
6. Began development of the $1/32^\circ$ Pacific thermodynamic finite depth model. Initial spin-up experiment is underway.
7. Assimilation studies with the $1/4^\circ$ Global model were performed. Comparisons between track by track and full field assimilation were studied.
8. Assimilation studies with the $1/16^\circ$ Pacific Basin model were performed. Twin experiments were completed for different combinations of satellite altimetry groundtracks for TOPEX/POSIEDON, ERS/2 and GEOSAT-Follow-On.

9. This project also contributed to the North Atlantic Basin modeling and NRL participation in ONR's Data Assimilation and Model Evaluation Experiment – North Atlantic Basin (DAMEE-NAB). That work is reported in the ONR report of collaborative 6.1 project, "North Atlantic Basin Modeling and Prediction for DAMEE/NAB".

RESULTS

1. The $1/16^\circ$ thermodynamic finite depth model produces a more accurate basin-wide SSH field than its hydrodynamic counterpart, especially in the subtropical gyre south of the Kuroshio and in the east-west gradient along the equator. The addition of NLOM software improvements has led to an overall increase in model stability when forced with interannually varying winds.
2. The wind-forced version of NLOM was able to accurately depict the 1997/98 El Niño when given accurate atmospheric forcing provided by the FNMOC NOGAPS surface stresses. Modeling this predominantly deterministic response to wind forcing is a first order requirement for any ocean model that plans to assimilate altimeter data. The ocean model and assimilation must work in tandem to produce an improved representation of reality, as the assimilation cannot be used to compensate for inaccurate ocean model dynamics. This work is highlighted in a feature article in the 1998 NRL Review.
3. The IBM SP is now the second most important platform, after the Cray T3E, for running large NLOM simulations. Biharmonic diffusion is routinely applied to layer thickness and density on all new simulations. The mixed layer within NLOM is still experimental, but substantial progress has been made on extending the original excellent agreement with observations in the Indian Ocean to the entire global ocean.
4. New diffusion scheme in NLOM is making the $1/32^\circ$ model more stable than previous scheme. Experimentation to determine the proper parameter space has been completed.
5. It was determined that full field assimilation for the $1/4^\circ$ Global model gave better results in some areas due to the coarse resolution of this model. Full field assimilation was implemented at FNMOC but both types of assimilation are still being run for continued testing.
6. Tests indicate that the track by track assimilation using nudging is a successful technique for the $1/16^\circ$ Pacific model. Further tests are being conducted with real altimetry data.

IMPACT/APPLICATIONS

1. The depiction of the 1997/98 El Niño in the wind forced version of NLOM indicates the ocean model has the proper ocean dynamics to simulate such events. It also points to the realistic wind forcing provided by the FNMOC NOGAPS model.
2. FY98 was the first year in which all NLOM simulations were run on scalable systems, i.e. none were run on Cray PVP systems. NLOM can run efficiently and interchangeably on a wide variety of computer platforms (e.g. CM5, Cray T3E, IBM SP, SGI Origin 2000, HP/Convex SPP2000), Cray PVP systems (e.g. C90, J90, T90) and workstations. So the complete switch from vector to scalable systems is an indication that the former are no longer competitive for the state of art ocean modeling.
1. Resolution for each variable of $1/16^\circ$ for the global ocean, $1/32^\circ$ for the Pacific north of 20°S and $1/64^\circ$ for the subtropical Atlantic (9° - 51°N), used in this project, are the highest to date for a global (basin-scale) ocean model. We are discovering an increasingly widespread importance of mesoscale flow instabilities in allowing bottom topography to steer major and minor upper ocean currents, as ocean model horizontal grid resolution is increased. The upper ocean currents do not need to impinge on the bottom topography for upper ocean - topographic coupling via mesoscale

flow instabilities to occur, and they don't impinge over much of the world ocean. However, this type of coupling does require that mesoscale variability be very well resolved to obtain sufficient coupling. Thus, this major topographic effect is missed at coarser resolution and can even lead to false conclusions about the role of topography and unexplained errors in simulations of the mean pathways of ocean currents, including the Gulf Stream and Kuroshio. Results so far suggest that this type of coupling is widespread outside the tropics and that $1/32^\circ$ resolution is required to obtain worldwide coverage with this type of coupling in the places where it occurs, although it has been obtained at lower resolutions in some regions.

4. In general, a critical issue in forecast system design is determining the resolution required. Ocean models require finer resolution and more computer time than atmospheric models in part because the space scales for variability due to the flow instabilities (oceanic mesoscale eddies vs. atmospheric highs and lows) are about 20-30 times smaller than found in the atmosphere. We need to resolve the oceanic eddy space scale very well because (1) it is relevant for most Navy applications, (2) these models need to provide high resolution boundary conditions for even higher resolution coastal models, (3) upper ocean – topographic coupling via flow instabilities has a major impact on the pathways of many upper ocean currents (including mean pathways) and very fine resolution of the flow instabilities is required to get sufficient coupling (Hurlburt, et al., 1996; Hogan and Hurlburt, 1997; Hurlburt and Metzger, 1998), (4) very fine resolution is required to obtain (a) inertial jets and sharp oceanic fronts which span major ocean basins as observed (Hurlburt, et al., 1996) and (b) the associated nonlinear recirculation gyres which affect the shape of the large scale ocean gyres (Hurlburt and Hogan, 1998), (5) it is necessary to resolve small islands and narrow passages which affect current pathways and current transports in many regions, (6) in data assimilative mode we do not want the ocean model to “fight” the data because the natural behavior of the ocean model is inconsistent with the observations, and (7) a very high resolution model is needed to help get an accurate mean sea surface height field to add to the deviations obtained from satellite altimetry (observations alone do not provide sufficient resolution to do this). Results so far indicate that $1/32^\circ$ is the most appropriate target resolution.
5. The $1/16^\circ$ Pacific nowcast/forecast system under development is the first component of a global eddy-resolving capability by the year 2000. The techniques being developed for this system will also be applicable for the $1/32^\circ$ NLOM in the subtropical Atlantic and a $1/8^\circ$ global system that will provide boundary conditions to the higher resolution basin-scale systems.

TRANSITIONS

A $1/4^\circ$ 6 layer finite depth thermodynamic global ocean model was transitioned to FNMOC in FY98 via the data assimilation group. This model is now running in real time with TOPEX/POSEIDON and ERS-2 altimetry data assimilation. The system is being prepared for OPTTEST and is expected to be operational in FY99. Also, an updated $1/16^\circ$ Pacific basin model was transitioned to the data assimilation group for assimilation experiments.

RELATED PROJECTS

Through this project and 6.1 North Atlantic Basin Modeling and Prediction for DAMEE, NRL participates in ONR's DAMEE-NAB project funded FY95-FY98, which includes participants from several universities. Other related research projects include 6.1 Dynamics of Low Latitude Western Boundary Currents, 6.1 Forced Upper Ocean Dynamics (mixed layer development), 6.1 Thermodynamic and Topographic Forcing in Global Ocean Models, 6.2 Monitoring the North Pacific

(National Ocean Partnership Program (NOPP)) (acoustic tomography focus), 6.3 Scalable Ocean Models with Domain Decomposition (Common HPC Software Support Initiative (CHSSI)), 6.4 Ocean Data Assimilation and 6.4 Large Scale Ocean Models.

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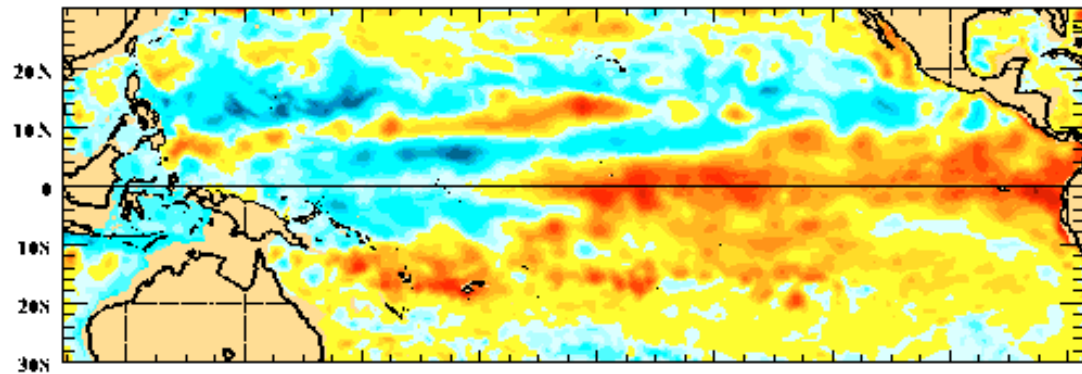
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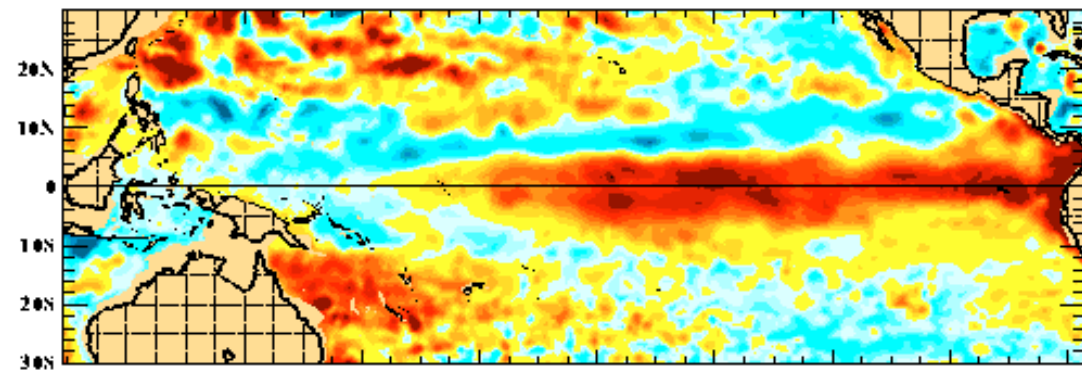
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**SSH anomaly from the 1/4° Global NLOM
for 24 October 1997**

NLOM without data assimilation



NLOM with assimilation of TOPEX/Poseidon altimeter data



TOPEX/Poseidon altimetry

